CLASSICAL METHODS OF LEFT VENTRICULAR CONTOUR EXTRACTION AND PREPROCESSING OF ECHOCARDIOGRAPHIC IMAGES : A REVIEW

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ABSTRACT

A main objective of digital processing of echocardiographic images is to improve the signal to noise ratio of the video images acquired from the ultrasound equipment along with contour extraction in order to obtain cardiac parameters. We present a review and comparison among the different proposed methods in the current literature for both noise removal and contour extraction of echocardiographic images. It is shown that classical methods do not render good contours and there is a need for a different approach to contour extraction algorithms.

INTRODUCTION

One of the most important topics in echocardiographic imaging is parameter extraction. Practically the complete set of parameters to be extracted from echocardiographic images may be attained easily once the walls of the cavities to be analyzed are marked. It is clear then, that the main objective is to detect closed contours from which cardiac parameters may be found.

Another related problem is the bad quality of the images obtained even with the newer ultrasound equipments. The great advantage that the use of non-intrusive methods offers is offset by a poor signal to noise ratio which makes very difficult to carry out a parametric analysis of cardiac structures. For this reason there has been a lot of effort dedicated to improve the quality of the echocardiographic views. This improvement as well as the contour extraction algorithms can be done at the RF level or at the video level. Most of the attempts so far have concentrated on preprocessing at the video level, mainly due to the difficulty of gaining access at the RF signal of the echocardiographic equipment. The contour extraction tasks have followed a similar way.

Despite of the wide variation in the results of the various preprocessing operators that have been employed in 2D echocardiography, there are very few data in the literature comparing the efficiency of the various approaches, for both preprocessing and contour extraction. Our first effort has been addressed towards a study and implementation of the most proposed methods for smoothing and image enhancement at the video level. After this comparison and according to the obtained results, it will be shown that there is a need for a different approach to contour extraction algorithms in echocardiographic imaging.

This work has been supported by NTE, S.A. under ESA contract 7320/87/NL/PP

Quantitative analysis of global and regional left ventricular function from 2D echocardiograms has been based upon manual identification of the endocardial and epicardial borders in the past years. Two well-known drawbacks of manually tracing cardiac borders are : tediousness and time required to perform this task, as well as substantial inter and intra-observer variability in measurements made from 2D echocardiograms in this fashion.

This has led a number of groups to investigate the application to image processing techniques for 2D echocardiographic edge detection. Most of the works have been oriented to a computer-assisted edge extraction approach. Some researchers have also published preliminary results of automated edge detection [1], but a reliable and efficient fully automated procedure for identifying cardiac borders on 2D echocardiograms has not been reached so far. In addition, almost all groups have limited their research to parasternal short-axis views where the contours to be extracted have simple and known circular shapes.

The first step that is usually carried out consists of image preprocessing to enhance apparent edges and/or reduce image noise to improve the accuracy of the subsequent edge detection steps. Histogram equalization, median filtering and spatial/temporal smoothing have been the most common techniques employed to accomplish this goal.

Our effort in this paper has been mostly dedicated to describe the methods, and due to the lack of space, nor visual results neither photographs will be shown.

SMOOTHING METHODS

One of the most proposed smoothing methods for echocardiogram enhancement is median filtering. The number of imaging fields where this technique has been successfully applied is broad, and its characteristics of removing noise without blurring images is wellknown. Median filtering has been applied to the test images with different window sizes and produces a satisfactory improvement in image quality while preserving edge components.

A recently developed adaptive version of median filtering termed CS (Comparison and Selection) algorithm was reported in [2]. Its principal feature resides in adding edge sharpening to the effects of median filtering. A parameter is given concerning the distance to the median value of the selected value in the window; increasing the index causes an emphasizing of the sharpening effect.

Extremum sharpening was proposed by Lester et al. in [3] to be applied in union with median filtering for preprocessing biomedical images. They recommended a sequence of median filtering, then extremum sharpening and again median filtering. Both operators were also applied to echocardiograms in [4] by Collins et al. In this case, median filtering was performed once after extremum sharpening.

Smoothing methods based on averaging only a selected group of NxN pixels in a window, have been developed to improve the results of the simpler uniform averaging technique. Among them the Ek operator has been used in echocardiogram enhancement [5]. We have tested two methods of this type : the local selective averaging algorithm based on the concept of relative similarity proposed by Yokoya et al. [6], and the edge preserving smoothing operator described by Nagao and Matzuyama [7]. Both methods produce a very similar output, but the second one is much less time-consuming since the former is a relatively slow iterative process.

A different approach is the hysteresis algorithm presented by Ehrich in [8] that reduce the impulsive noise contained in the image according to the standard type one-dimensional hysteresis smoothing. A parameter related to the noise level must be specified to the algorithm. While the method removes some noise, the image suffers an appreciable distortion.

An interesting method for noise removal is proposed by Nakagawa and Rosenfeld in [9] that uses a chain of local MIN and MAX operations. They proved that these operators in gray-level pictures are the analog of the "shrinking" and "expanding" operators in binary images. These operations commute with thresholding : thus if they are applied to a gray-scale image, followed by thresholding, the result is the same as if the image were first thresholded and shrinking, and expanding were then performed. The results show that since many zero-intensity pixels are distributed around due to low gain setting, the black regions are expanded destroying some valuable information.

Finally, a smoothing method based on low-pass filtering in the frequency domain has been studied. Gaussian filter was chosen among the different filters of this class. The cut frequency and attenuation parameters were investigated in some range. Similar results may be obtained by iterating a spatial averaging operator. Adjusting the parameter values allows pleasant images to be formed, but the characteristic blurring effect of low-pass filtering is however present.

While all these methods do remove some noise and visually enhance the image, some techniques can be discarded due to their poor results, excessive processing or difficulty to fix appropiate parameters. Thus, Nagao's edge preserving smoothing, hysteresis and MIN-MAX operators have been set apart.

Median filtering is considered to be an effective preprocessing task as it eliminates speckle noise present in echocardiograms without blurring the image. CS filter and extremum sharpening add some local edge sharpening to median smoothing, but the usefulness of this feature for cardiac contour extraction is not clear since some distorting effects are introduced. Gaussian filtering and simple averaging must be taken into account although both methods produce an appreciable blurring effect.

CONTOUR EXTRACTION METHODS

Two alternative approaches have been proposed for object contour extraction. The first one, which is generally referred to as edge detection, consists of first applying an edge detector operator followed by a chain of processes (thresholding, thinning, linking, tracking, ...), some of them optional depending on the characteristics of the image and the used operator, with the aim of obtaining a binary map of continuous and thinned edges. The second approach is based on first applying an image segmentation algorithm to produce a labeled map of connected regions, and then tracking and drawing the boundaries between adjacent regions. This latter technique, usually termed region segmentation or region extraction, guarantees that no isolated edge segments will be present in the final contour map.

Some researchers have proposed to take adavantage of the convergence between both approaches (edge/border coincidence) for helping the selection of optimal segmentation thresholds or alternatively to separate object contours from noisy edges.

Edge detectors

In order to improve the performance of contour detection, some preprocessing has been considered. From the methods described in the former section, median filtering has been selected since it is proved to eliminate speckle noise while preserving edge information and produces good visual quality. Hence the test images have been smoothed by 5x5 median filtering.

Operators for edge detection can be classified, according to the scope of the information used to detect an edge element, into three groups: local, regional and global operators. Some representative methods of each class have been applied to the test images.

Among the local operators, those based on spatial differentiation are the simplest and best known ones [10,11]. The first order differential operators by Roberts and Sobel, besides the Laplacian of second order, have been studied. The Laplacian operator causes even the smallest details in the image to stand out creating unconnected edges with a very rough texture.

Robinson [12], Prewitt and Kirsch have proposed the template type operators which estimate edge strength and direction from the maximum output value of eight differential-type masks provided. The results obtained from these operators are all identical to that produce by Sobel. When applied to the test images, their output looks like a spaghetti soup with a lot of micro-edges contouring local echoes.

Frei and Chen proposed a method using nine orthogonal vectors in feature space [13]. The results of applying this technique are quite different from the previous ones. Although it seems to detect some parts of the endocardium border, its behaviour is just like tracking the boundary after thresholding with a value near zero. This characteristic has led us to test the method with a negative version of the picture, and as expected, the resulting contours belong to the epicardial border zone where the echo intensity is saturated. Adding both outputs, a more complete edge image is achieved.

Finally, the last local detector investigated has been the Entropy edge operator described in [14] by Shiozaki. It is a nonlinear spatial filter that detects edges by computing local brightness entropy and discriminating regions where the change of brightness is severe from those where is smooth. The entropy operator is rotationally invariant as is the Laplacian. The results of applying the Entropy operator coincide closely with those of Frei and Chen, but the Entropy operator seems to be more sensitive to noise.

Among the regional operators, Hueckel, Mero-Vassy and difference of averages have been studied. Hueckel's method analytically determines the edge model parameters using polar coordinate Fourier type masks. It has a high computational cost compared to the simple differential operators already mentioned, but it performs better producing a cleaner image with thin edges and less noisy edges. The Mero-Vassy operator is a simplified version of the former using two base masks [15]. It works like a differential type detector for small regions, but for larger regions the results are worse than those of Hueckel method.

Enhancement of lines and curves

The output of the edge detectors is generally filtered by processing which try to eliminate noise components and create long lines and curves. In this category there are two major methods : (1) enhancement based on relationships in neighbour elements in the image space, and (2) enhancement based on clustering in the parameter space of the lines and curves to be extracted. In method (1) we find iterative edge detection methods, directional thinning, and relaxation methods applied to the enhancement of lines and curves. Different methods have been tested here. Among the most representatives the Kasvand iterative edge detector, the Eberlein iterative method and the relaxation labeling technique have been tested. If simple curves (straight lines, circles, ellipses) are searched for, then methods based on the Hough transform and clustering in the parameter space (2) can be used at the expense of a high computational cost. Duda and Hart proposed a representative method which expresses straight lines with parameters of slope and origin-offset and obtains lines by counting on the parameter plane.

The techniques studied in this section have not yielded any significant improvement with respect to the edge detectors results. The use of non-maximum absorption (Eberlein algorithm) after a regional gradient (difference of averages) edge detector produces the best edge enhanced image.

Connection of edge elements

A third category of algorithms concerns the connection of edge elements to extract smoother and longer contours. Some of them involve defining an evaluation function (heuristic) from knowledge or constraints related to the sequence of elements to be detected, and performing graph or tree search techniques to find an optimum path. these adege tracking methods are usually very expensive in both time and space resources due to combinatory explosion of possible paths. Martelli's algorithms [16] and Ashkar-Modestino's have been studied. Martelli's method uses a graph heuristic search. The start and end points of the search and the coefficients for each term in the evaluation function are specified by the operator. The technique proposed by Ashkar and Modestino in uses a tree heuristic search. Other simpler methods for edge linking that require no backtracking have been proposed. One example is the "ridge riding" algorithm.

None of the connection of edge elements methods are able to provide global cardiac borders. As a conclusion, it can be said that the methods are not appropiate for echocardiographic imaging.

Image segmentation and boundary tracking

Image segmentation algorithms range from simple global thresholding of the grey level histogram to clustering in a multidimensional characteristic feature space. The aim is usually to reduce the image information to a set of labeled regions from which the size, shape and geometrical issues can be extracted. Global thresholding has been employed in earlier works on contour extraction from echocardiograms with some degree of success to separate cavities form myocardium. Variable (or dynamic) thresholding is described by Nakagawa and Rosenfeld.

Region extraction methods (also termed region growing represent a different way of doing the segmentation. They divide the image into a set of connected regions by clustering pixels in the image plane while referring to the feature domain. Region extraction techniques can be broken down into three categories : region growing by merging, region dividign and split & merge.

Edge/Border coincidence

Milgram proposed to take advantage of the convergence between edge detection and segmentation for helping the selection of optimal thresholds. Despite this method is attractive, if the segmentation is not enough accurate, little benefit can be achieved to help edge linking. In the case of echocardiograms, as both edge detection and image segmentation approaches fail to extract a clean and precise object contour, these methods do not yield any interesting accomplishment.

CONCLUSIONS AND PROPOSALS

The main conclusion of this study is that traditional approaches in image processing for contour extraction on static images, that do not use any a priori information concerning what is expected to find in the image, clearly are unable to extract by themselves the cardiac borders of interest in 2-D echocardiograms. This is due, basically, to the low SNR, echo dropout, and the spotted-like structure in ultrasound images that causes multiple noisy and sinuous edges to be detected.

If a preprocessing method to further improve the quality of the images were to be selected, we would suggest 5x5 median filtering followed by histogram equalization. This combination provides speckle noise removal as well as image enhancement. Some temporal/spatial smoothing methods have been tested but no dramatic improvement has been found over the static case. Among those methods median filtering has also shown the best results. Concerning contour detection none of the "Classical" methods provides closed contours. Thus a specific method and new approaches to echocardiographic imaging need to be developed. To that extend a new algorithm has been introduced which renders excellent automatic closed contours. This new approach and proposed algorithm are presented in a companion paper in these same Proceedings. Please see : "Automatic left ventricular contour extraction and volume calculation from echocardiographic images" by A. Gasull et al.

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